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The use of the flashiness index as a possible indicator for nutrient loss prediction in agricultural catchments

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A characterisation of the hydrological behaviour of four small agricultural catchments in Estonia and Norway was carried out using a flashiness index (FI). FI reflects the frequency and rapidity of short term changes in runoff values. A comparison of FIs based on hourly and average daily discharge indicated large within-day variations over very short time intervals. Large differences were observed between the Norwegian and Estonian catchments, irrespective of whether average daily discharge or hourly discharge values were used. A comparison of the FI and the base flow index (BFI) showed that high FI values corresponded to low BFI values. Norwegian catchments with high FI or low BFI values showed high nutrient losses, whereas the contrary was observed for the Estonian catchments. Although the FI does not *a priori* give information about the flow processes within catchments, we believe that the FI, as well as the BFI, might be helpful in explaining differences in nutrient and soil losses between catchments.

Introduction

Agriculture contributes a significant portion of the nutrient load to the environment, being to a large degree responsible for the eutrophication of inland surface waters and coastal zones in the Nordic and Baltic countries (Stålnacke 1996, HELCOM 2004). Several authors (e.g. Kauppi 1979, Rekolainen 1989, Keeney and DeLuca 1993, Johnes and Heathwaite 1997, Zabłocki and Pieńkowski 1999, De Wit 2000, Mander *et al*. 2000, Vagstad *et al*. 2004, Iital *et al*. 2005) have described the relative importance of different factors that influence the loss of nitrogen and phosphorus from catchments, e.g. landuse and spatial location of nutrient sources in the catchment, fertilization rate, livestock density, topography and soil type.

It is well known that nutrient losses, especially nitrogen, are well correlated with variations in discharge (Stålnacke and Grimvall 2000). However, when comparing the results of different water quality monitoring programmes, under otherwise almost similar climatological conditions and agricultural practices, large differences in nutrient losses can be observed. Donohue *et al*. (2005) emphasized that risk of diffuse nutrient emissions to surface waters is not static, but varies over short timescales and among catchments. Deelstra *et al*. (2005) found in a Latvian catchment a decrease in nitrogen concentration with an increase in catchment scale. In addition to a decrease in fertiliser application rates, it was concluded that also flow processes had an important impact on water chemistry. Similar findings were made by Tiemeyer *et al*. (2006) when studying nutrient losses in artificially drained catchments.

Comparing nutrient losses measured in small agricultural catchments in the Baltic and Nordic countries, Vagstad *et al*. (2004) found that catchments having a large contribution of groundwater runoff in the total runoff, in general had lower nitrogen losses. This is an indication of possible interactions between flow processes (e.g. slow flow or fast flow) and the microbiological and chemical processes, determining the nutrient losses at catchment scale. Deelstra *et al*. (1998) showed that longer residence times in the Latvian and Estonian catchments partly could explain the lower nitrogen losses in a comparison of runoff recession periods in Latvian, Estonian and Norwegian catchments. Due to longer residence times, the soil is maintained saturated or near saturated for longer periods which in turn can lead to anaerobic conditions and a possible increase in denitrification rates. Generally, artificial drainage of agricultural land can lead to an increase in nitrate-nitrogen runoff. However, its magnitude is very much influenced by e.g. soil type and drainage system (Skaggs *et al*. 1980, Gilliam and Skaggs 1986). Gambrell *et al*. (1975) showed that undisturbed, poorly drained soils with relatively high water tables showed less loss in nitrate-nitrogen as compared with naturally well-drained soils, mainly as a result of denitrification.

Analyses on measured runoff can be carried out to differentiate between fast and slow flow processes in the catchment. One methodology is the determination of the Base Flow Index (BFI), i.e. the contribution of the slow flow or groundwater flow in the total runoff measured at the catchment outlet (Gustard *et al*. 1992, Arnold and Allen 1999), whereas other methods can be based on the analysis of runoff recession curves (Tallaksen 1995) or on the use of tracers. The calculations are usually carried out on the basis of average daily discharges, thereby not taking into account the in-day variation in discharge, often present in smaller catchments. Baker *et al*. (2004) developed a flashiness index (FI) which they used to describe changes in the hydrological behaviour of rivers in response to changes in land use. In this case the term flashiness reflects the frequency and rapidity of short term changes in daily runoff values.

In our study we used the same index and applied it to both the average daily discharge as well as to hourly discharges measured on small agricultural catchments in Estonia (Räpu, Rägina) and Norway (Skuterud, Mørdre). The objective is to use the flashiness index as a tool to better understand flow processes thereby contributing to an improved understanding of the nutrient loss processes.

Material and methods

Catchments description

The main characteristics of the four studied agricultural catchments are summarised in Table 1. The Norwegian catchments Mørdre and Skuterud are part of the Agricultural Environmental Monitoring Programme in Norway (JOVA). Both catchments are rather similar in size and are located in the south-east of Norway, approximately 50 km north and 35 km south of Oslo, respectively. The Estonian catchments Räpu and Rägina, which are part of the Estonian environmental monitoring programme, are located approximately 150 km south and south-west of Tallinn, respectively. The Estonian catchments are about four times the size of the Norwegian catchments.

The long term mean annual temperature is lowest in Mørdre, followed by Skuterud, Räpu and Rägina (Table 1). During the observation period Mørdre had the lowest temperature, whereas Rägina had the highest temperature, which is consistent with the long term mean annual temperature (Table 2). There was little difference in the average monthly air temperatures during the observation period (Fig. 1). Based on the observed yearly temperature distributions it is likely that precipitation in November–March can appear as snow and that no major differences in snow accumulation during the winter season are

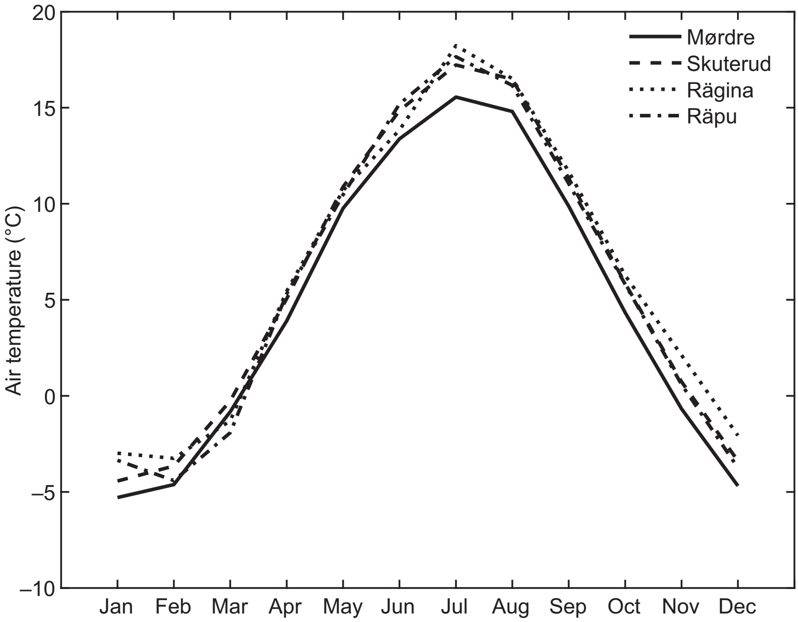

Fig 1. Average monthly air temperatures for Mørdre, Skuterud, Räpu and Rägina during the observation period.

expected. Skuterud and Mørdre have the highest and lowest long term annual precipitation, respectively. During the observation period the highest average annual precipitation was observed at Skuterud and Mørdre. Large variations between the different years occurred (Table 2). There was also a considerable variation in monthly precipitation between catchments (Figs. 2–5).

The topography of the catchments varies from flat to hilly, with the largest range in elevation in the Norwegian catchments. Soil types on the arable land in the Skuterud catch-

Table 1. Main catchment characteristics.

	Räpu, Estonia	Rägina, Estonia	Skuterud, Norway	Mørdre, Norway
Size (ha)	2550	2130	450	680
Long-term mean annual temperature (monthly maximum/minimum) (°C)	4.8 (16.2/–6.5)[1]	5.2 (16.3/–5.5)[1]	5.3 (16.8/–4.8)[3]	4.0 (15.0/–6.9)[4]
Long term annual precipitation (mm)	742[2]	683[2]	785[3]	665[4]
Elevation range (m a.s.l.)	59–65	15–25	91–146	130–237
Land use (%)	arable (77), forest (21), bog (2)	arable (53), forest (47)	arable (61), forest (29), urban (8), bog (2)	Arable (65), forest (28), bogs (4), urban (3)
Soil texture	coam	clay loam	silt loam, silty clay loam, silt loam, loamy sand	silt, silt loam, silty clay loam
Main crops	cereals, ley	ley, cereals, potato	cereals, ley	cereals, ley
N/P fertiliser (kg ha^{-1})	60/9	30/4	120/30	130/22
Number of livestock units (ha^{-1})	0.5	0.18	0.21	0.23

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[3] Norwegian University of Life Sciences (1961–1990), Ås.
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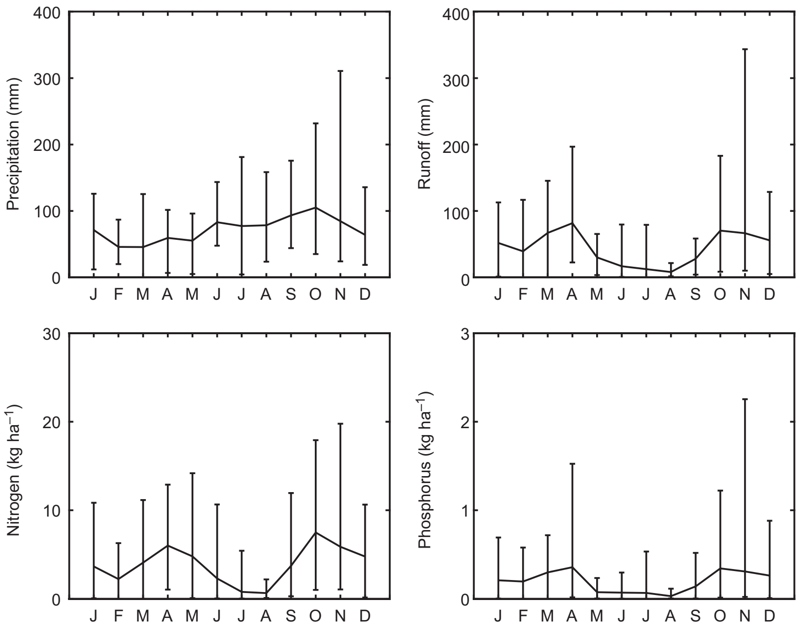

Fig. 2. Measured precipitation and runoff, and calculated total nitrogen and total phosphorus loss in the Skuterud catchment during the monitoring period (bars indicate maximum/minimum values).

ment are dominated by marine silty clay loam deposits in addition to a lesser part with marine sand and moraine deposits. The main soil type in the Mørdre catchment is dominated by a silt loam soil, interchanged by land-levelled marine clay soils. The Räpu catchment is dominated by loamy soils, considered to be some of the best agricultural soils in Estonia. The soils in the Rägina catchment are mainly of a clay loam texture.

Agriculture is the main land use in the catchments, with fertiliser levels being considerably higher in the Norwegian catchments. Arable land constitutes 61% and 65% of the total area in the Skuterud and Mørdre catchments, respectively, whereas forest occupies 29% and 28%. In the Rägina catchment arable land and natural grasslands constitute 35% and 18%, respectively. Forest occupies almost 50%. For Räpu the share of arable land is 77%, the rest being forest and bog areas. In all four catchments cereals is the dominating arable crop. Most of the agricultural land in the catchments is artificially drained. Skuterud and Mørdre are most intensively drained, with a drain spacing of 8 m and a drain depth 0.8–1 m. The Räpu and Rägina catchments have in general a drain spacing of 20 m and a drain depth of 1 m below soil surface.

Discharge measurement and water sampling

In all four catchments the discharge was measured using a triangular profile two-dimensional weir referred to in the literature as the Crump weir (Crump 1952). Water levels were recorded automatically using a pressure transducer in

Table 2. Precipitation and air temperature in the catchments in Norway and Estonia.

Catchment	Precipitation (mm)			Temperature (°C)			Period
	mean	max	min	mean	max	min	
Skuterud	862	1192	651	5.9	7.1	4.2	1994–2004
Mørdre	712	930	575	4.6	6.1	3.2	1992–2004
Rägina	695	881	518	6.3	7.1	5.9	2000–2004
Räpu	668	752	609	5.8	6.9	4.4	1997–2004

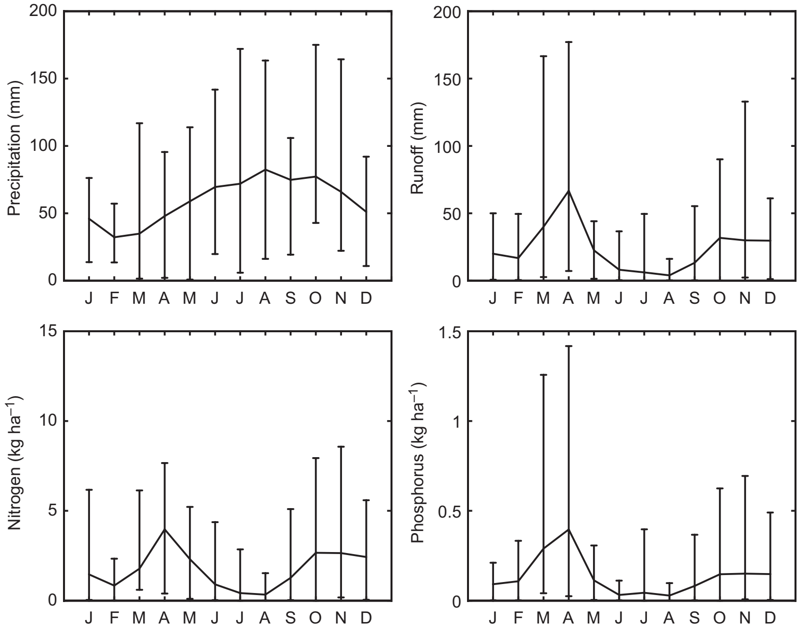

Fig. 3. Measured precipitation and runoff, and calculated total nitrogen and total phosphorus loss in the Mørdre catchment during the monitoring period (bars indicate maximum/minimum values).

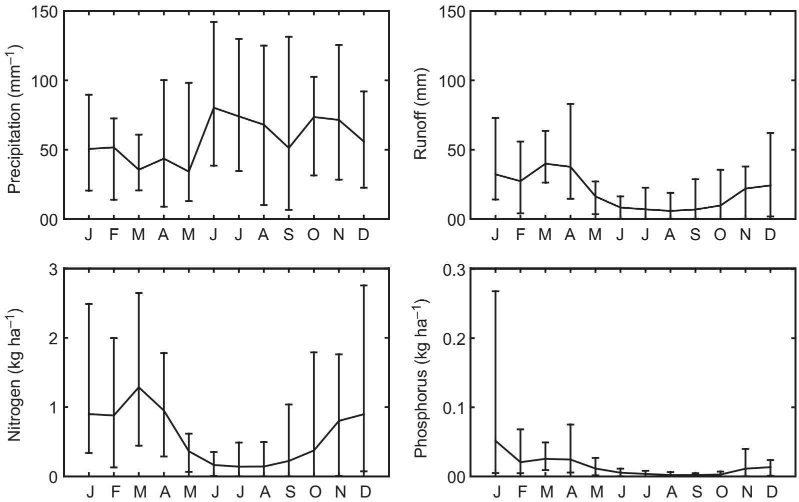

Fig. 4. Measured precipitation and runoff, and calculated total nitrogen and total phosphorus loss in the Räpu catchment during the monitoring period (bars indicate maximum/minimum values).

combination with a Campbell data logger. Based on the head–discharge relation for the measurement structure, the discharge was recorded every minute and average-hourly as well as maximum and minimum discharges were stored in the data logger. Composite water samples were collected automatically on a volume proportional basis (Deelstra and Øygarden 1998, Deelstra *et al*. 1998). In principle, water samples were analysed every fourteen days, however during periods with extreme runoff conditions samples could be collected more frequently. The samples were analysed for among others total nitrogen (TN), nitrate, total phosphorus (TP) and phosphate. During winter periods, ice formation was prevented by heating lamps or cables and more frequent maintenance, thereby guaranteeing year-round reliable discharge measurements.

The nutrient load for a sampling period was calculated on the basis of the measured discharge and concentrations of compounds in composite samples as follows:

$$L = \sum_{t=1}^{n} C \times q_t \qquad (1)$$

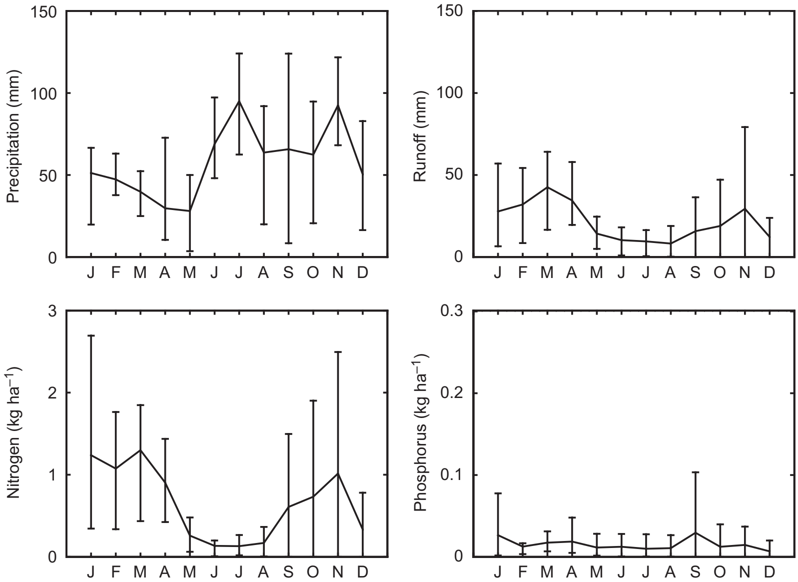

Fig. 5. Measured precipitation and runoff, and calculated total nitrogen and total phosphorus loss in the Rägina catchment during the monitoring period (bars indicate maximum/minimum values).

where L = total load during sample period, C = concentration in composite sample for time period $t = 1$ to $t = n$, q_t = hourly discharge at time t, n = number of hours represented by the composite sample period.

If no composite sample was collected due to malfunction or freezing of equipment, a grab sample was taken instead. In this case the concentration data were obtained through interpolation between the two last sampling dates. Total yearly load is the sum of all loads during the respective composite sampling periods.

The flashiness index

Flashiness, or rate of change, refers to how quickly flow changes from one condition to another and has been widely used to describe urban hydrology. James (1965) described the hydrographs of individual floods rising and falling more sharply under urban conditions. Based on the data from earlier studies, Hollis (1975) concluded that the hydrologic response of urban land is "flashier" than the response of undeveloped land due to the increased volume and speed of runoff. Ward (1981) described flashiness as the ratio of the river flow observed for at least 30% of the time to that observed for more than 70% of the time: the Q30/Q70 statistics. Baker *et al*. (2004) developed a flashiness index which was used to detect changes in the hydrological regime of rivers. The flashiness index (Eq. 2) is obtained by calculating the total pathlength of flow and divide it by the sum of the average daily discharges. The total pathlength is equal to the sum, usually over one year, of the absolute values of the day to day changes in the average daily discharge values.

$$\mathrm{FI}_{\mathrm{day}} = \frac{\sum_{i=1}^{n} \left| q_i - q_{i-1} \right|}{\sum_{i=1}^{n} q_i} \quad (2)$$

where q_i and q_{i-1} are the average daily discharges ($m^3 s^{-1}$) on day i and day $i-1$, respectively. The index is dimensionless meaning that similar results are obtained when replacing the discharge ($m^3 s^{-1}$) by the runoff per unit area (m) or total daily discharge volumes (m^3). To obtain the flashiness index for the different months during a year, the monthly pathlength is calculated and divided by the sum of the average daily discharges over one year. When the flashiness index is based on average daily discharge values, it does not take into account the in-day variation in discharge, which under specific conditions can vary considerably during a day (Fig.

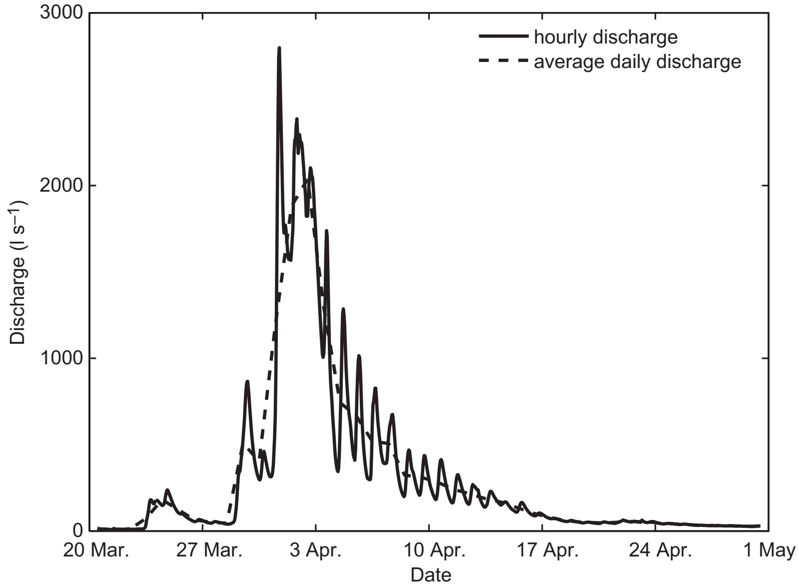

Fig. 6. Flashiness of discharge in the Skuterud catchment, Norway.

6). Therefore a further modification has been implemented to obtain a flashiness index based on hourly discharge values (FI_{hr}). In this case the total path length is the sum of the differences between the hourly discharge values (Eq. 3).

$$FI_{hr} = \frac{\sum_{i=1}^{n} |\Delta q_{hr}|}{\sum_{i}^{n} q_i} \quad (3)$$

Baker *et al*. (2004) tested the effect of using hourly instead of daily average discharge values and found a considerable increase in the FI due to an increase in the total pathlength by a factor 1–3.

Base flow index

For the Norwegian and Estonian catchments also the baseflow index (BFI) has been calculated. The BFI is a measure of the proportion of groundwater flow in the total runoff measured at the catchment outlet. In our case we used the method developed by Gustard *et al*. (1992), which is based on a smoothed minima technique. The BFI was calculated on the basis of average daily discharge values and for a period of one year.

Results

Runoff and nutrient losses

The average yearly runoff was highest in Skuterud and lowest in the Räpu catchment. Also the variation in yearly runoff was highest in Skuterud catchment and lowest in the Räpu catchment. This corresponds to the variation in annual precipitation (Table 2). In general, the largest part of the total annual runoff occurred outside the growing season, from September–March. The highest loss of TN and TP also occurred outside the growing season (Figs. 2–5). The Norwegian catchments had the highest annual TN loss. The average annual TN loss for the Skuterud and Mørdre catchment was 46.3 and 21.0 kg ha^{-1}, respectively, as compared with 7.9 and 6.7 kg ha^{-1} for the Rägina and Räpu catchments, respectively (Table 3). The annual TP loss for the Norwegian catchments varied from 1.6 to 2.4 kg ha^{-1}, as compared with 0.2 kg ha^{-1} for the two Estonian catchments. For the Norwegian catchments, the highest nitrogen runoff occurred during the period from September–December and in March and April, just before the onset of the growing season. The high loss of nitrogen after the growing season is most likely due to favourable conditions for nitrification and the

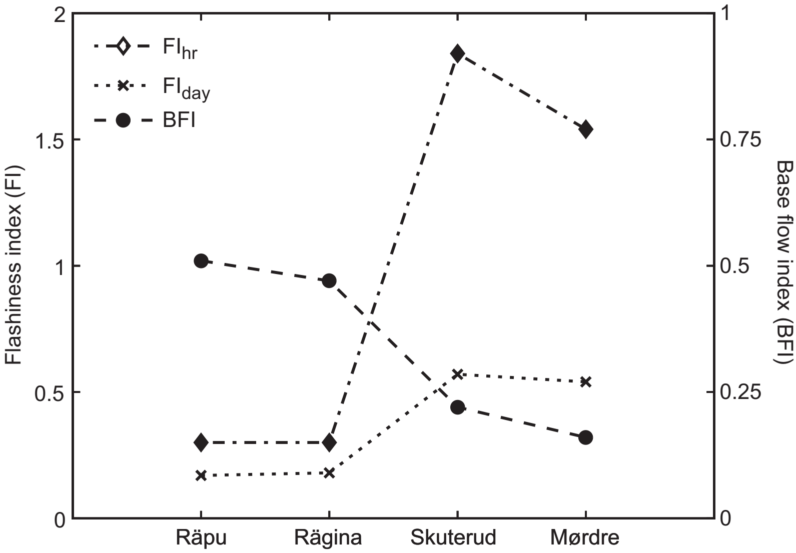

Fig. 7. Average values for flashiness indices and base flow index in studied Norwegian and Estonian catchments.

subsequent leaching through excess precipitation. The highest phosphorus loss occurred in January–April, related to conditions of snowmelt and partly frozen soils, causing erosion and the subsequent loss of phosphorus. In the Estonian catchments, the highest nitrogen loss occurred during the period from January–April. Phosphorus loss was highest in January–April in the Räpu catchment, whereas more evenly distributed between the different periods for the Rägina catchment. High nitrogen and phosphorus loss occurred during periods with high runoff. Iital (2005) concluded that more than two thirds of nitrogen and phosphorus load was transported out of the catchment during the 3–4 month period during the late winter–early spring.

Flashiness and base flow index

There were large differences between the two countries when comparing the daily (FI_{day}) and hourly (FI_{hr}) values, with the Estonian catchments having low values for both indices compared to the Norwegian catchments (Table 3). The average FI_{hr} values were significantly larger than the average FI_{day}, indicating substantial in-day variations between hourly discharges. The results for both the Estonian and Norwegian catchments show that a flashiness index based on average daily discharge values may "hide" the real flashiness in the runoff. The results also show a significant difference in BFI between the Estonian and Norwegian catchments. For the

Table 3. Mean annual precipitation, mean annual temperature, measured runoff, calculated total nitrogen (TN) and total phosphorus(TP) loss in agricultural catchments in Norway and Estonia.

Catchment	Runoff (mm)			TN loss (kg ha^{-1})			TP loss (kg ha^{-1})			Period
	mean	max	min	mean	max	min	mean	max	min	
Skuterud	526	919	278	46.3	70.4	27.7	2.4	5.8	0.9	1994–2004
Mørdre	288	502	162	21	35.9	12.7	1.6	3.9	0.9	1992–2004
Rägina[1]	256	347	211	7.9	10.3	5.9	0.2	0.4	0.1	2000–2004
Räpu[2]	237	375	161	6.7	13.3	3.7	0.2	0.3	0.1	1997–2004

[1,2] Results for runoff, TN and TP for 2003[(1] and 1998[(2] not included due to malfunctioning of station during winter period.

Skuterud and Mørdre catchments the average BFI was 0.22 and 0.16, respectively, whereas the BFI for Räpu and Rägina was 0.51 and 0.47, respectively (Table 4). A comparison of the FI and the base flow index (BFI) showed that high FI values corresponded to low BFI values and *vice versa* (Fig. 7).

Discussion

The differences between the Estonian and Norwegian catchments are probably related to the relative importance of the dominating flow processes in runoff generation caused by differences in topography, subsurface drainage intensity, soil types and possibly scale effects. For both the Norwegian and Estonian catchments, the flashiness indices showed little variation irrespective of the yearly runoff. Similar findings were made by Baker *et al*. (2004). A good relation between the monthly discharge and monthly FI index was obtained with months having high discharges also showing a high flashiness index (Fig. 8). This is in agreement with the findings of Baker *et al*. (2004) who reported a good relation between the yearly pathlength and the annual discharge.

There are relatively large differences in altitude in the studied Norwegian catchments compared to the Estonian catchments. Topography can seriously affect surface runoff induced erosion processes leading to phosphorus loss (Ahuja *et al*. 1982, Bechmann *et al*. 2004). Surface runoff processes will be further enhanced during winter periods with frozen soils, which can seriously impede the infiltration capacity. Differences in winter conditions between the Norwegian and Estonian catchments could have an effect on these processes. However, on the basis of the observed temperatures during the measurement periods, no major differences in average air temperatures were observed during the winter period (Fig. 1). Under Nordic soil and weather conditions, runoff and erosion are documented to be highest during winter and especially during the snowmelt periods. During these periods, erosion is caused by surface runoff from melting water and not from rainfall and raindrop detachment (Øygarden, 2000). Lundekvam (1998) concluded that for Norway, melt water, causing surface runoff, is the most serious reason for erosion in addition to near-saturated soil moisture conditions after longer periods with rainfall during autumn. The P content in the Estonian soils is still high despite the decreased fertilisation rates compared to the 1980s (Vagstad *et al*. 2000, Stålnacke *et al*. 2004). Haraldsen *et al*. (2001) found no significant differences in Al-extractable P in soil samples in selected Estonian and Norwegian fields. The high amount of phosphorus loss is an indication of the large proportion of surface runoff in the Norwegian catchments as compared with that in the Estonian catchments (Table 3). This will also contribute to a more "flashy" nature in runoff, reflected in a higher FI and lower BFI for the Norwegian catchments (Table 4). It is likely that due to the flat topography, a major part of excess water will infiltrate the soil in Estonian catchments, which will retard the runoff generation.

Clay soils in general are characterised by low values for the saturated hydraulic conductivity. However, a major contributor in runoff generation can be macropore flow through the soil profile. In a study carried out on clay soils in Norway, Øygarden *et al*. (1997) concluded that macropore flow contributed significantly to both runoff and soil loss. In an experiment carried out on small plots dominated by clay soils, Culley *et al*. (1992) measured significant loss of phosphorus and sediments through the tile drainage systems, which is an indication of macropore flow. Amstrong and Garwood (1991) noticed a rapid response in runoff on clay soils, often with multiple peaks reflecting the variation in rainfall intensities. They concluded that the rapid response was caused by macropore flow. Inoue (1993) found large differences between the saturated hydraulic conductivity from laboratory measurements and values obtained from hydrograph recession analysis, respectively, attributing the difference to macropore flow. Also Kværnø and Deelstra (2002) found large differences between the saturated and near saturated hydraulic conductivity in the Skuterud catchment, based on measurements using the tension infiltrometer, indicating the presence of macropores in the top soil. The Norwegian catchments are dominated by clay soils, and infiltration and flow processes through macropores can have contributed to the

Table 4. The flashiness index, based on average daily (FI_{day}) and hourly discharge values (FI_{hr}) in addition to the base flow index (BFI) and annual runoff in four agricultural catchments in Norway (Skuterud, Mørdre) and Estonia (Räpu, Rägina).

	Skuterud				Mørdre				Räpu				Rägina			
Year	FI_{day}	Fi_{hr}	BFI	Runoff (mm)	FI_{day}	Fi_{hr}	BFI	Runoff (mm)	FI_{day}	Fi_{hr}	BFI	Runoff (mm)	FI_{day}	Fi_{hr}	BFI	Runoff (mm)
1992					0.63	1.73	0.14	250								
1993					0.71	1.89	0.10	231								
1994	0.48	1.61	0.08	461	0.35	1.25	0.25	311								
1995	0.55	1.54	0.32	501	0.58	1.68	0.19	259								
1996	0.68	2.29	0.18	277	0.52	1.14	0.17	285								
1997	0.56	1.92	0.19	292	0.59	1.84	0.12	161	0.18	0.26	0.50	208				
1998	0.49	1.51	0.26	485	0.54	1.32	0.16	283	–*							
1999	0.63	2.09	0.25	699	0.51	1.59	0.18	390	0.17	0.41	0.36	198				
2000	0.52	2.05	0.32	916	0.55	1.54	0.19	502	0.16	0.25	0.53	176	0.16	0.24	0.59	214
2001	0.56	2.13	0.17	606	0.51	1.88	0.12	242	0.21	0.35	0.50	205	0.19	0.32	0.35	347
2002	0.68	1.97	0.21	525	0.59	1.93	0.15	270	0.15	0.25	0.51	161	0.15	0.28	0.57	211
2003	0.55	1.46	0.27	524	0.37	0.67	0.22	200	0.21	0.35	0.55	265	–*			
2004	0.52	1.68	0.17	481	0.57	1.6	0.13	366	0.14	0.22	0.64	354	0.2	0.34	0.37	250
Mean	0.57	1.84	0.22	524	0.54	1.54	0.16	288	0.17	0.30	0.51	224	0.18	0.30	0.47	256
CV	0.12	0.16	0.32		0.18	0.24	0.26		0.16	0.24	0.17		0.14	0.15	0.27	

* Measurements not included due to malfunctioning of monitoring station during winter period.

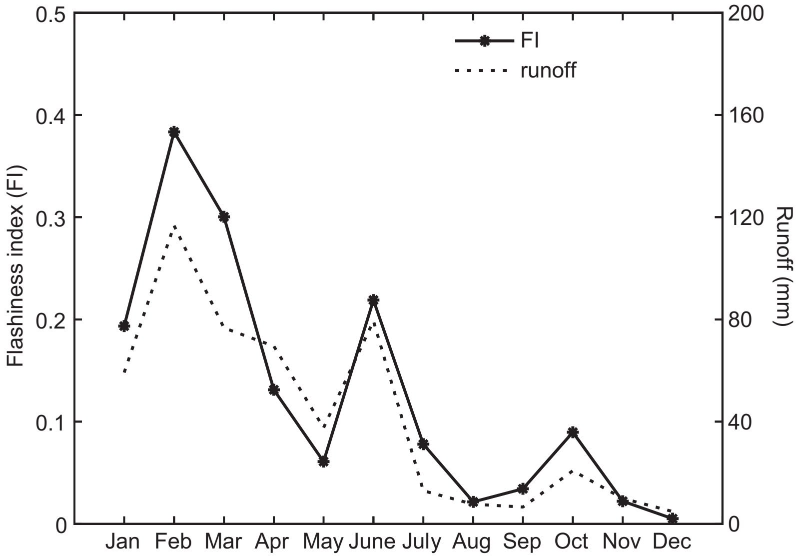

Fig. 8. Flashiness index (FI_{hr}) and monthly runoff for the Skuterud catchment during 1995.

higher phosphorus losses as compared with those in the Estonian catchments. In addition, it is assumed that macropore flow contributes to the differences in FI and BFI.

Due to the flat topography of the Estonian catchments a significant amount of excess precipitation can occur as subsurface flow. However, due to the large drain spacing a considerable part of the infiltrated water might bypass the subsurface drainage system and appear as base flow runoff at the catchment outlet. This will prolong the retention time, enhancing the differences in FI and BFI between the Norwegian and Estonian catchments. Prolonged retention times can have considerable effects on the nitrogen loss. Iital and Loigu (2001) observed higher concentrations of nitrate in subsurface drainage water as compared to concentrations in stream water. These differences can be attributed to either buffering processes in the main channels or denitrification in the groundwater system. Similar findings were made by Kladivko *et al.* (2004) who showed that drain flow and nitrogen loss per unit area increased with narrower drain spacings. In a study carried out by Skaggs *et al.* (1995) it was concluded that wider drain spacings lead to shallower groundwater tables and reduced nitrogen loss due to an increase in denitrification. Wesström (2002) showed that denitrification also can be artificially enhanced through controlled drainage, a management system in which the groundwater table is artificially raised, thereby increasing the soil moisture conditions and denitrification. The less "flashy" nature of the discharge in the Estonian catchments can be partly caused by the larger drain spacings and can, at least partly, explain the lower nitrogen runoff in the Estonian catchments (Table 3).

In their analysis of a large number of catchments with varying sizes, Baker *et al.* (2004) concluded that an increase in catchment area lead to a decrease in the flashiness index even though each size class showed a considerable variation in flashiness index. In our case, the size of the Estonian catchments is approximately three to four times the Norwegian catchments. This could explain the differences in FI values. However, in an analysis carried out on catchments in Norway comparable in size to the Estonian catchments, Deelstra *et al.* (2007) obtained flashiness indices similar to the FI values obtained for the Skuterud and Mørdre catchment. This confirms the findings by Baker *et al.* (2004) that considerable variation can exist in each size class.

Conclusions

It is evident that a thorough understanding of the hydrological processes and flow pathways for water and nutrients is necessary in the implementation of cost effective river basin management plans within the EU Water Framework Directive and in selection of adequate measures to achieve at least good ecological status of water bodies by 2015. Monitoring results from agricultural catchments in Norway and Estonia show large differences in nutrient runoff from agricultural dominated catchments. These differences cannot only be explained by the different fertilisation rates and land use properties. It is well known that hydrology can contribute significantly to these variations. Large differences in FI were found between the Estonian and Norwegian catchments, irrespective of whether average daily discharge or hourly discharge values were used. A comparison of the FI and the BFI showed high FI values corresponding to low BFI values and *vice versa*. Our results indicate that the runoff is generated by different flow processes. Although the FI does not *a priori* give information on the flow processes it is believed that the FI, as well as the BFI, might be helpful in explaining differences in nutrient and soil losses between catchments.

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